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Investigating the scale of herding in Chalcolithic pastoral communities settled along the Danube River in the 5th millennium BC: A case study at Borduşani-Popină and Hârşova-tell (Romania)

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ABSTRACT

In southeastern Romania, the Gumelniţa culture is characterized by the appearance of tell sites. Whether this phenomenon was accompanied by increasing specialization of the economy may be investigated through the zooarchaeology of pastoral systems. The scale of herding is an important element of this framework. A case study was conducted on the tell sites of Hârşova and Borduşani-Popină situated in the Danube River basin. Both sites, located respectively on a terrace of the river and on the island of Balta Ialomiţei, delivered occupations from the Gumelniţa A2 dated to the second half of 5th millennium cal BC. Their occupants subsisted on an economy focused to a large extent on aquatic resources but also heavily dependent on cattle, pig and caprines husbandry and agriculture. The role of riverbanks resources in herding strategies and the extent to which the island of Balta Ialomiţei may have sustained domestic animal stocks was addressed through stable isotope analysis of animal skeleton remains. At both sites, results revealed local herding for cattle and caprines, reflected in an unexpectedly high contribution of C_4 plants to their diet, most likely from ruderal C_4 plants that are more abundant around the settlements as well as in cultivated fields. Domestic pigs had a higher trophic status than their wild counterparts, highlighting a significant contribution of animal protein to their diet most likely provided by human activities, suggesting that they were maintained in the settlement. Overall the findings suggest domestic stocks were reared in close proximity to the settlements, rather than in an extensive system. This scheme complements the small-scale cultivation system highlighted from the archaeobotanical analysis. Gumelniţa tell sites have been previously described as being part of larger pastoral systems including locations with complementary functions, although functional complementarity in time was not made explicit in this model. In this regard, the results obtained at Hârşova and Borduşani-Popină are not in favour of large-scale seasonal mobility.

1. Introduction

In southeast Romania, the Chalcolithic period witnessed the appearance of tell sites, part of a phase of increasing social complexity that characterizes the 5th millennium BC in South-East Europe. The extent to which changes in social organisation were accompanied by increasing specialization at the settlement scale and the establishment of structured exchanges networks may be approached from the subsistence economy, in particular through the zooarchaeology of pastoral systems (Bréhard and Bălăşescu, 2012). The scale of herding, from household keeping to extensive keeping of larger herds, is one element of this framework (Halstead, 1996), which may be investigated namely from the place of livestock in the anthropic ecosystem. This includes location of pastures in the surrounding landscape and animal status in the food web. Stable isotope studies may help addressing these specific points

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(Balasse, 2014). In the present study, this approach was applied to Hârşova-tell and Borduşani-Popina, which are among the largest zooarchaeological assemblages for the Romanian Chalcolithic.

Hârşova-tell and Borduşani-Popina, situated in southeast Romania (Fig. 1), are among the largest Chalcolithic tell sites excavated in Romania to date (Popovici et al., 2000, 2001, 2003). Radiocarbon dates on animal bones set the Chalcolithic occupation of both sites to the second half of the 5th millennium cal BC (Bréhard and Bălăşescu, 2012; Gillis et al., 2013), which is consistent with previous radiocarbon dates for the Gumelniţa A2 phase.

The Hârşova-tell site is located on a terrace of the Danube River in Dobrudja province, Constanşa County. It was estimated that the tell originally extended over approximately 2 ha. Borduşani-Popină is in Muntenia province, Ialomiţa County. The site is located on the large island of Balta Ialomiţei, bordered by the Danube River on the western side and the Borcea on the eastern side. The distance between both sites is 20.5 km. The topography is different on the Danube side and the Borcea side of Balta Ialomiţei. The eastern side, where Hârşova-tell lies, is protected from seasonal floods by its elevated height, whereas the western side is periodically flooded over several kilometres. The topography of Ialomiţa island has suffered over the last 50 years from great anthropic impact, including diking, intensive agriculture, deforestation and tree plantation. Today, 15–20 % of the island's original surface is not protected by dams. In these areas, floods penetrate to the island 2.5–4 km.

The modern vegetation of Balta Ialomiţei is typical of a floodplain and river valley environment with a mosaic of riparian forests, coppices, meadows and marshes. *Populus* and *Salix* predominate in the river valley forests, while oak forests (*Quercus*, *Ulmus*) occupy the most elevated non-floodable riverbanks. Although the present day vegetation was intensely altered by human impact, a general similarity in the landscape, strongly structured by the presence of the Danube River, may be suggested between modern and Chalcolithic times. However, the forest component on the high riverbanks was probably more widespread in prehistoric times because of weaker anthropogenic pressure. Archaeobotanical analysis of wood charcoals recovered at Borduşani-Popină highlighted the dominance of hydrophilic species among which poplar, willow and elm dominate while oak predominates in fossil wood used in constructions (Tomescu, 2003). The wild mammals and avifauna also reflects a mosaic of lacustrine and forested areas (Moise, 1997; Bălăşescu et al., 2003; Gal and Kessler, 2003).

Evidence of agriculture was found at both sites and the recovered cultivated plants are typical of the Chalcolithic period in southeastern Europe. At Hârşova-tell, agriculture is indicated indirectly by a set of tools, including red deer antler pickaxes, flint sickle blades, and grinding stones (Popovici and Rialland, 1996). The analysis of carpological remains from one domestic deposit revealed the presence of cultivated cereals and pulses. Cereals include three wheat species (einkorn wheat, emmer wheat and bread wheat) and naked barley. Pulses are very well represented, especially bitter vetch, lentil and peas. It is uncertain whether bitter vetch was used as fodder, but its abundance in a domestic space deposit highly suggests it was a component of human diet. Hârşova-tell inhabitants also consumed wild fruits from common grape vine, cornelian cherry, elder and water caltrop. The presence of numerous seeds from the goosefoot (*Chenopodium album*) suggests it was used in diet. This ruderal species may have been largely available in the direct vicinity of the establishment.

The assemblage of cultivated plants from Borduşani-Popină has a very similar spectrum to that described at Hârşova-tell, with cereals including hulled wheats (einkorn, emmer) free-threshing wheat and naked barley, four cultivated pulses (lentil, bitter vetch, pea and grass pea) and grape. The presence of a large reserve of bitter vetch seeds stored in vessels is remarkable. Such deposits were found in other Gumelniţa sites in Romania and Bulgaria, indicating intentional cultivation (Monah, 1998–2000). Gathering activities in Borduşani-Popină are reflected by the presence of plum stones, oak acorns, elder nutlets, grape pips and water caltrop nuts remains.

The excavations conducted since 1993 have furnished large zooarchaeological assemblages. At Borduşani-Popina and Hârşova-tell, aquatic resources (mainly fish and bivalves, but also gastropods, crustaceous, amphibians, reptiles and birds) constituted a substantial part of the subsistence economy. Among mammals determined to the species, domestic animal remains dominate (>70%), highlighting the importance of husbandry for these communities. At Borduşani-Popina pigs dominate the domestic stock in numbers of remains, followed by cattle and caprines. At Hârşova-tell, caprines yielded the highest number of remains, pigs hold the second position, followed by cattle (Bălăşescu et al., 2005a). At both sites, exploitation of milk is suggested from the cattle mortality profile, while caprines were exploited for meat, with a focus on tender meat (Bréhard and Bălăşescu, 2012). Hunting targeted a diverse range of wild fauna. Wild boar is best represented, followed by the red deer and roe deer. Other wild species each contributed less than 1% of mammal remains (Bălăşescu et al., 2005a).

The aim of the study is to specify the place of stock rearing within the surrounding landscape. Were domestic stocks from Borduşani-Popină maintained on the island, were they herded on

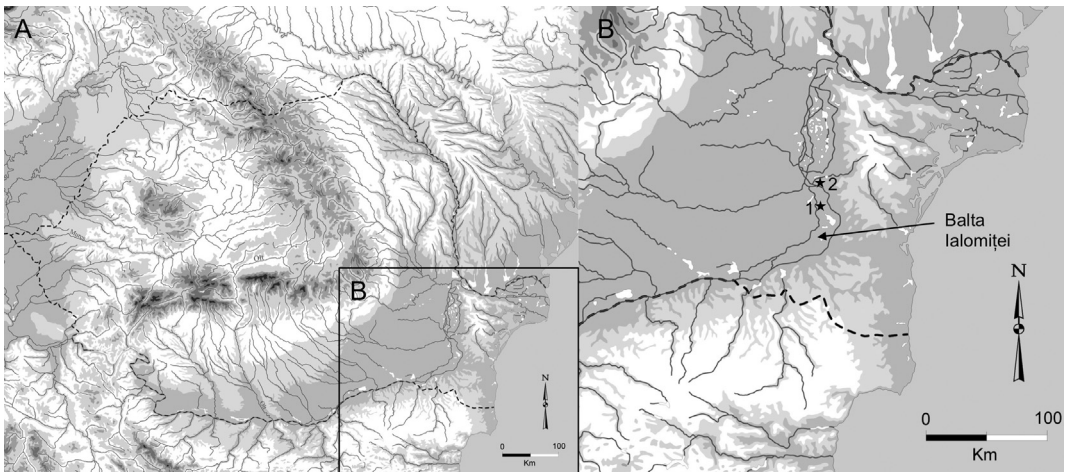

Fig. 1. Location of the sites. 1: Borduşani-Popină; 2: Hârşova-tell.

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the riverbanks or further away in the steppe? Did the communities from Borduşani-Popină and Hârşova-tell adopt similar or different choices in terms of husbandry practices? This was addressed through stable isotope analysis of animal skeleton remains. Stable nitrogen ($\delta^{15}N$), carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotope ratios in bone collagen and tooth enamel mineral fraction (bioapatite) are incorporated into the skeleton from diet and drinking. They are inherited from the plants in the ecosystem whose $\delta^{15}N$ and $\delta^{13}C$ values depend on physiological, edaphic and climatic factors, and from meteoric water whose $\delta^{18}O$ value depends on geographical and climatic factors, some of which may be influenced by seasonality. Although they have passed through the filter of animal metabolism and physiology, the isotopic signals retrieved in skeleton remains constitute valuable records of paleoecology (Koch, 1998). This information refers to individual life histories, and when retrieved from domestic animals it may be used to investigate husbandry practices and economic strategies (Balasse, 2014).

2. Material and methods

Previous stable isotope analyses on the large cattle bone assemblage from Borduşani-Popină had demonstrated very good preservation of bone collagen at this site (Gillis et al., 2013), which augured well for the bone assemblage from Hârşova-tell with similar burial conditions. At both sites, the study included domestic animals and the main representatives of the wild fauna. The maximum number of individuals were sampled by choosing the skeletal part which best represented each species in the assemblage. Sequential analysis of cattle and sheep teeth was meant to investigate diet and environmental factors at the seasonal scale. At present, more analysis has been conducted at Borduşani-Popină, and only a few teeth from Hârşova-tell were added for comparison. An analysis of a wider assemblage has begun and will be the subject of further publications.

Collagen was extracted from wild and domestic animal bones from Borduşani-Popină (45 specimens) and Hârşova-tell (64 specimens). Those belong to sheep, cattle, pig, wild boar, beaver, red deer, roe deer, auroch, and wild horse (Tables 1 and 2). All bones belong to different individuals and were from adult animals. These are added to 17 previous bone collagen extracts from subadult and adult cattle from Borduşani-Popină (Gillis et al., 2013, dental stages 3–5). Among bovines and suids, domestic and wild taxa were distinguished using morphometrical criteria (Degerbøl and Fredskild, 1970; El Susi, 1996; Manhart, 1998; Bălăşescu et al., 2005a).

Table 1
List of bone specimens sampled for collagen analysis at Borduşani-Popină. Species identification, skeleton part (R right, L left), amount of bone used for extraction, extraction yield (mg collagen/g bone), collagen carbon (%C) and nitrogen (%N) contents, collagen carbon:nitrogen atomic ratio (C:N), collagen nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope compositions.

Sample	Species	Skeleton part	Bone wt (mg)	Yield (mg/g)	% C	% N	C/N	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
PBORD Ovis 65	*Ovis aries*	Hemimandible R	379	117	42.1	15.4	3.2	+7.8	−18.5
PBORD Ovis 67	*Ovis aries*	Hemimandible R	383	129	39.9	14.6	3.2	+7.1	−19.3
PBORD Ovis 68	*Ovis aries*	Hemimandible R	377	72	39.2	14.5	3.2	+7.7	−19.5
PBORD Ovis 69	*Ovis aries*	Hemimandible R	360	106	39.1	14.2	3.2	+8.8	−16.8
PBORD Ovis 70	*Ovis aries*	Hemimandible R	364	103	40.8	14.8	3.2	+7.8	−19.1
PBORD Ovis 71	*Ovis aries*	Hemimandible R	327	97	39.9	14.4	3.2	+7.1	−19.1
PBORD Ovis 72	*Ovis aries*	Hemimandible R	375	114	42.3	15.2	3.3	+7.4	−18.5
PBORD Sus MB1	*Sus s. domesticus*	Humerus L	296	123	39.5	14.4	3.2	+10.3	−21.1
PBORD Sus MB2	*Sus s. domesticus*	Humerus L	282	130	39.2	14.2	3.2	+8.4	−20.9
PBORD Sus MB3	*Sus s. domesticus*	Humerus L	282	123	39.3	14.2	3.2	+8.8	−19.9
PBORD Sus MB4	*Sus s. domesticus*	Humerus L	294	130	38.5	14.0	3.2	+9.7	−20.5
PBORD Sus MB5	*Sus s. domesticus*	Humerus L	286	122	38.3	14.1	3.2	+8.7	−20.5
PBORD Sus MB6	*Sus s. domesticus*	Humerus L	290	128	39.4	14.2	3.2	+9.9	−20.3
PBORD Sus MB7	*Sus s. domesticus*	Humerus L	291	125	39.7	14.5	3.2	+8.0	−21.1
PBORD Sus MB8	*Sus s. domesticus*	Humerus L	285	135	40.0	14.5	3.2	+7.7	−19.4
PBORD Sus MB9	*Sus s. domesticus*	Humerus L	280	105	38.2	13.7	3.2	+6.7	−20.4
PBORD Sus MB10	*Sus s. domesticus*	Humerus L	311	121	39.6	14.3	3.2	+9.8	−20.6
PBORD Sus MB11	*Sus s. domesticus*	Humerus L	284	124	38.7	14.1	3.2	+10.0	−21.1
PBORD Sus MB12	*Sus s. domesticus*	Humerus L	284	47	36.1	13.3	3.2	+8.6	−19.5
PBORD Sus MB13	*Sus s. domesticus*	Humerus L	288	nd	38.5	14.0	3.2	+7.4	−20.7
PBORD Sus MB14	*Sus scrofa*	Humerus R	301	106	39.8	14.6	3.2	+7.5	−20.3
PBORD Sus MB15	*Sus scrofa*	Humerus R	297	142	39.7	14.4	3.2	+8.3	−20.7
PBORD Sus MB16	*Sus scrofa*	Humerus R	282	54	37.1	13.5	3.2	+7.5	−20.9
PBORD Sus MB17	*Sus scrofa*	Humerus R	285	nd	38.5	14.3	3.2	+7.4	−20.2
PBORD Sus MB18	*Sus scrofa*	Humerus R	285	88	38.3	13.8	3.2	+7.7	−20.6
PBORD Sus MB19	*Sus scrofa*	Humerus R	295	118	39.7	14.4	3.2	+8.4	−21.2
PBORD Sus MB20	*Sus scrofa*	Humerus R	287	67	37.7	13.6	3.2	+8.4	−20.4
PBORD Sus MB21	*Sus scrofa*	Humerus R	318	102	39.7	14.5	3.2	+7.8	−19.9
PBORD Castor 1	*Castor fiber*	Femur G	382	115	39.0	14.3	3.2	+8.9	−21.6
PBORD Castor 2	*Castor fiber*	Femur D	349	129	41.3	15.2	3.2	+8.1	−21.6
PBORD Castor 3	*Castor fiber*	Femur D	362	102	40.9	14.9	3.2	+7.5	−21.7
PBORD Castor 4	*Castor fiber*	Femur D	346	108	40.9	15.1	3.2	+8.4	−21.5
PBORD Cervus 1	*Cervus elaphus*	Radius L	364	26	31.4	11.4	3.2	+5.4	−20.4
PBORD Cervus 2	*Cervus elaphus*	Radius L	360	105	39.7	14.6	3.2	+6.1	−20.2
PBORD Cervus 3	*Cervus elaphus*	Radius L	350	138	40.4	14.9	3.2	+5.5	−20.8
PBORD Cervus 4	*Cervus elaphus*	Radius L	352	92	39.1	14.3	3.2	+6.1	−20.2
PBORD Cervus 5	*Cervus elaphus*	Radius L	349	121	40.0	14.7	3.2	+6.1	−20.6
PBORD Cervus 6	*Cervus elaphus*	Radius R	350	148	39.8	14.6	3.2	+5.3	−20.6
PBORD Bos MB1	*Bos primigenius*	Humerus R	376	143	42.7	15.7	3.2	+6.4	−20.4
PBORD Bos MB2	*Bos primigenius*	Humerus R	305	148	40.2	14.9	3.2	+6.1	−20.5
PBORD Bos MB3	*Bos primigenius*	Hemimandible R	301	114	41.7	15.4	3.1	+5.9	−20.4
PBORD Equus 1	*Equus ferus*	Radius R	366	136	42.4	15.6	3.2	+3.8	−21.2
PBORD Capreolus 1	*Capreolus capreolus*	Hemimandible L	356	87	39.7	14.6	3.2	+5.7	−21.7
PBORD Capreolus 2	*Capreolus capreolus*	Hemimandible L	401	86	39.9	14.7	3.2	+6.9	−21.6
PBORD Capreolus 3	*Capreolus capreolus*	Hemimandible L	362	90	38.6	14.2	3.2	+6.9	−22.9

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Table 2
List of bone specimens sampled for collagen analysis at Hârşova-tell. Species identification, skeleton part (R right, L left), amount of bone used for extraction, extraction yield (mg collagen/g bone), collagen carbon (%C) and nitrogen (%N) contents, collagen carbon: nitrogen atomic ratio (C:N), collagen nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope compositions.

Sample	Species	Skeleton part	Bone wt (mg)	Yield (mg/g)	% C	% N	C/N	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
HVA Bos 5	*Bos taurus*	Humerus L	304	128	40.6	14.8	3.2	+6.4	−19.3
HVA Bos 6	*Bos taurus*	Humerus L	334	86	39.2	14.3	3.2	+7.7	−18.8
HVA Bos 7	*Bos taurus*	Humerus L	308	65	36.6	13.4	3.2	+7.4	−18.9
HVA Bos 8	*Bos taurus*	Humerus L	303	94	36.7	13.6	3.2	+6.3	−20.9
HVA Bos 9	*Bos taurus*	Humerus L	301	83	39.0	14.2	3.2	+7.8	−18.1
HVA Bos 10	*Bos taurus*	Humerus L	324	99	40.8	14.9	3.2	+7.5	−20.9
HVA Bos 11	*Bos taurus*	Humerus L	302	28	35.5	12.8	3.2	+9.2	−16.1
HVA Bos 12	*Bos taurus*	Humerus L	322	43	29.3	10.6	3.2	+5.1	−19.9
HVA Ovis 76	*Ovis aries*	Hemimandible L	305	45	39.3	14.3	3.2	+7.0	−19.2
HVA Ovis 85	*Ovis aries*	Hemimandible L	325	57	39.9	14.3	3.3	+6.8	−19.1
HVA Ovis 86	*Ovis aries*	Hemimandible L	314	74	40.4	14.4	3.3	+6.9	−18.7
HVA Ovis 87	*Ovis aries*	Hemimandible L	299	101	39.5	14.3	3.2	+8.5	−18.9
HVA Ovis 90	*Ovis aries*	Hemimandible L	320	92	39.3	14.1	3.2	+6.5	−19.8
HVA Ovis 91	*Ovis aries*	Hemimandible L	300	83	37.2	13.4	3.2	+7.8	−18.6
HVA Ovis 92	*Ovis aries*	Hemimandible L	318	90	40.0	14.3	3.3	+6.8	−19.7
HVA Ovis 93	*Ovis aries*	Hemimandible L	296	99	42.6	15.4	3.2	+7.0	−20.0
HVA Ovis 96	*Ovis aries*	Hemimandible L	337	55	37.8	13.7	3.2	+6.5	−19.5
HVA Ovis 98	*Ovis aries*	Hemimandible L	304	95	41.3	14.9	3.2	+6.8	−18.1
HVA Sus 1	*Sus scrofa*	Humerus R	311	79	41.1	15.1	3.2	+7.6	−21.4
HVA Sus 2	*Sus scrofa*	Humerus R	304	86	41.0	14.6	3.3	+5.7	−20.1
HVA Sus 3	*Sus scrofa*	Humerus R	307	77	40.2	14.6	3.2	+8.5	−21.1
HVA Sus 4	*Sus scrofa*	Humerus R	314	91	40.4	14.9	3.2	+7.3	−20.9
HVA Sus 5	*Sus scrofa*	Humerus R	319	115	41.0	15.1	3.2	+7.7	−20.6
HVA Sus 6	*Sus scrofa*	Humerus R	301	38	38.3	14.2	3.1	+7.7	−21.0
HVA Sus 7	*Sus scrofa*	Humerus R	309	95	41.1	15.1	3.2	+7.4	−20.3
HVA Sus 8	*Sus scrofa*	Humerus R	314	87	40.8	14.9	3.2	+8.8	−21.2
HVA Sus 9	*Sus scrofa*	Humerus R	305	49	40.1	14.9	3.2	+6.8	−20.9
HVA Sus 10	*Sus scrofa*	Humerus R	312	81	40.8	15.0	3.2	+8.4	−20.8
HVA Sus 11	*Sus scrofa*	Humerus R	307	90	40.4	14.7	3.2	+6.8	−21.0
HVA Sus 12	*Sus scrofa*	Humerus R	307	55	39.2	14.5	3.2	+8.3	−20.2
HVA Sus 13	*Sus scrofa*	Humerus R	337	37	38.3	14.0	3.2	+7.6	−19.8
HVA Sus 14	*Sus scrofa*	Humerus R	302	47	39.8	14.6	3.2	+7.8	−20.9
HVA Sus 15	*Sus s. domesticus*	Humerus R	304	33	37.8	13.8	3.2	+6.8	−21.3
HVA Sus 16	*Sus s. domesticus*	Humerus R	318	82	40.0	14.8	3.1	+7.6	−19.9
HVA Sus 17	*Sus s. domesticus*	Humerus R	312	37	39.0	14.3	3.2	+8.1	−20.5
HVA Sus 18	*Sus s. domesticus*	Humerus R	313	33	39.2	14.2	3.2	+9.0	−20.3
HVA Sus 19	*Sus s. domesticus*	Humerus R	318	66	40.2	14.8	3.2	+8.6	−20.0
HVA Sus 20	*Sus s. domesticus*	Humerus R	323	62	40.9	14.9	3.2	+8.6	−19.1
HVA Sus 21	*Sus s. domesticus*	Humerus R	307	81	40.4	14.7	3.2	+8.6	−19.7
HVA Sus 22	*Sus s. domesticus*	Humerus R	320	96	41.9	15.2	3.2	+9.5	−20.5
HVA Sus 23	*Sus s. domesticus*	Humerus R	306	80	40.8	15.0	3.2	+7.9	−20.6
HVA Sus 24	*Sus s. domesticus*	Humerus R	313	44	39.0	14.2	3.2	+8.9	−19.6
HVA Sus 25	*Sus s. domesticus*	Humerus R	305	68	43.4	15.0	3.4	+10.0	−19.9
HVA Sus 26	*Sus s. domesticus*	Humerus R	308	93	43.3	15.4	3.3	+8.5	−19.8
HVA Sus 27	*Sus s. domesticus*	Humerus R	304	26	36.9	13.2	3.3	+7.6	−19.8
HVA Sus 28	*Sus s. domesticus*	Humerus R	325	39	39.6	14.3	3.2	+8.9	−21.4
HVA Sus 29	*Sus s. domesticus*	Humerus R	322	86	42.8	15.4	3.2	+8.8	−20.4
HVA Sus 30	*Sus s. domesticus*	Humerus R	302	88	43.6	15.7	3.3	+8.3	−20.8
HVA Sus 31	*Sus s. domesticus*	Humerus R	318	78	40.8	14.9	3.2	+8.6	−20.5
HVA CEEL 1	*Cervus elaphus*	Humerus R	312	73	42.3	15.5	3.2	+5.6	−21.1
HVA CEEL 2	*Cervus elaphus*	humerus R	321	76	40.2	14.6	3.2	+5.7	−20.6
HVA CEEL 3	*Cervus elaphus*	Humerus R	326	101	43.6	15.7	3.2	+6.6	−19.8
HVA CEEL 4	*Cervus elaphus*	Humerus R	316	5	40.6	14.4	3.3	+6.2	−20.7
HVA CEEL 5	*Cervus elaphus*	Humerus R	327	87	37.8	13.8	3.2	+6.6	−20.8
HVA CEEL 6	*Cervus elaphus*	Humerus R	306	39	41.7	15.0	3.2	+6.0	−20.2
HVA CEEL 7	*Cervus elaphus*	Humerus R	324	60	41.1	15.0	3.2	+7.3	−22.0
HVA CPCP 1	*Capreolus capreolus*	Hemimandible R	330	70	40.7	14.7	3.2	+7.1	−21.2
HVA CPCP 2	*Capreolus capreolus*	Hemimandible L	314	51	41.8	15.0	3.2	+7.6	−21.6
HVA CPCP 3	*Capreolus capreolus*	Hemimandible L	313	74	42.0	15.4	3.2	+6.2	−21.2
HVA Equus 1	*Equus ferus*	Humerus R	313	75	38.4	13.9	3.2	+4.1	−21.1
HVA Bos 1	*Bos primigenius*	Humerus R	318	115	40.2	14.6	3.2	+7.4	−20.3
HVA Bos 2	*Bos primigenius*	Humerus L	318	49	37.0	13.5	3.2	+7.7	−19.4
HVA Bos 3	*Bos primigenius*	Humerus L	317	81	39.3	14.4	3.2	+7.2	−20.3
HVA Bos 4	*Bos primigenius*	Humerus L	305	69	40.0	14.5	3.2	+6.3	−20.1

In suids, the size criterion traditionally used on skeleton elements to distinguish between small domestic pigs from larger wild boars was recently challenged by a study suggesting that shape is more powerful than size to pursue this goal (Evin et al., 2015a). When applied to Romanian Neolithic and Chalcolithic assemblages, geometric morphometric analyses of suid molars revealed the presence of a group of individuals with large domestic shaped molars, besides the two expected groups with small domestic

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shape molars on the one side – domestic pigs – and large wild shape molars on the other side – wild boars. Such individuals with large domestic shape molars are noted at Borduşani-Popină and Hârşova-tell (Evin et al., 2015b). However, because the stable isotope analyses were conducted on humerus (at the time when this study was designed, the recent results from geometric morphometrics were unknown), the large domestic shape suids defined using geometric morphometrics on dental remains cannot be matched to the stable isotope data. Consequently, while there is not any questioning about the domestic status of the small suids, "pigs", the large suids, "wild boars", may as well include some of these large individuals carrying domestic phenotypes. Presently, the status of these suids in terms of their relationship to the human communities, functionally domestic or wild, regardless of their ancestry, is unknown. Stable isotopes may contribute significantly to this debate, and research in this direction is currently being conducted jointly by the authors of both studies.

Collagen was extracted from approximately 280 to 400 mg of bone powder, following the procedure described in Bocherens et al. (1991). Coupled measurements of $\delta^{15}N$ and $\delta^{13}C$ were conducted on 400–500 μg of collagen on an elemental analyser Thermo Flash 2000 interfaced to a Thermo DeltaVAdvantage IRMS. The analytical precision, determined from 11 to 17 analyses of an alanine standard within each run, varies from 0.08 to 0.22‰ for $\delta^{13}C$ and from 0.07 to 0.19‰ for $\delta^{15}N$, and from 0.1 to 0.5% for C content and from 0.1 to 0.3% for N content. Over the course of all analyses, the alanine standard gave mean values of +0.55 ± 0.16‰ for $\delta^{15}N$ (N = 90, expected value = +0.59‰), −21.01 ± 0.92‰ for $\delta^{13}C$ (N = 90, expected value = −22.16‰), 15.8 ± 0.2% for N content (N = 75, expected value = 15.72%) and 40.6 ± 0.4% for C content (expected value = 40.44%).

Analyses of stable oxygen and carbon isotope ratios ($\delta^{18}O$ and $\delta^{13}C$) were performed on enamel bioapatite. Because enamel is not remodelled once fully mineralized, the tooth holds a record of the animal's isotopic history over the duration of crown formation. In large herbivores, the formation of molars crowns spans several seasons to over a year, giving access, through sequential analysis along tooth crown, to management of diet and environment at the seasonal scale. The analysis focused on cattle and sheep teeth from Borduşani-Popină (eight cattle and six sheep molars) and Hârşova-tell (one cattle and two sheep molars). Two previously analysed cattle molars from Borduşani-Popină (Gillis et al., 2013) are added to this new dataset. For comparison, teeth from wild herbivores (red deer, roe deer and aurochs) were also analysed according to the same procedure. The sequential sampling was conducted on the vestibular side of each tooth, on the first lobe of cattle and aurochs lower third molars (M3); on the second lobe on sheep lower M3; on the middle lobe of the red deer lower M3; on the first lobe of the roe deer lower second (M2) and third molars. Each sample is positioned in the tooth crown by its distance from the enamel–root junction (ERJ). After pre-treatment (Balasse et al., 2003), enamel samples of approximately 600 μg were reacted with orthophosphoric acid at 70 °C for 240 s in individual vessels in an automated cryogenic distillation system (Kiel IV device), interfaced with a DeltaVAdvantage IRMS. Over the period of analysis, 139 runs of our laboratory internal carbonate standard (Marbre LM) gave an average $\delta^{13}C$ value of +2.05 ± 0.02‰ (theoretical value normalized to NBS 19 = +2.13‰) and an average $\delta^{18}O$ value of −1.63 ± 0.05‰ (theoretical value normalized to NBS 19 = −1.83‰). The analytical precision within each run, calculated from six to 11 measurements of the standard Marbre LM, varies from 0.01 to 0.03 ‰ for $\delta^{13}C$ and from 0.01 to 0.06 ‰ for $\delta^{18}O$. When evaluating the difference in stable isotope values between taxa, statistical significance was tested using the Wilcoxon rank test, setting the significance p-values <0.05.

3. Results

3.1. Collagen preservation

All selected bones yielded collagen. Collagen extraction yields vary from 26 to 148 mg/g at Borduşani-Popină (average ±1σ = 110 ± 27 mg/g) and from 26 to 128 mg/g at Hârşova-tell (except HVA CEEL 4 - which only yielded 5 mg/g; average = 71 ± 25 mg/g). The carbon and nitrogen contents (% C and % N) of the bone collagen extracts from Borduşani-Popină vary respectively from 31 to 43 % (average 39 ± 2%) and from 11 to 16 % (average 14 ± 1%) with atomic C:N ratios of 3.1–3.3 (Table 1). At Hârşova-tell, the carbon and nitrogen contents of bone collagen extracts vary respectively from 29 to 44 % (average 40 ± 2%) and from 11 to 16 % (average 14 ± 1%) with atomic C:N ratios of 3.1–3.4 (Table 2). All extracts satisfy the criteria defined for reliable stable carbon and nitrogen isotope ratios (DeNiro, 1985; Ambrose, 1990).

3.2. Bone collagen $\delta^{13}C$ values

Results from bone collagen stable isotope measurements are reported in Tables 1 and 2 and Fig. 2a and b. The $\delta^{13}C$ values measured in wild fauna vary from −22.9 to −19.9‰ at Borduşani-Popină and from −22 to −19.4‰ at Hârşova-tell. They do not differ significantly at both sites (W = 326, p = 0.53). Considering mean $\delta^{13}C$ values of −27‰ and −12.5‰ for modern C_3 and C_4 plants respectively (Vogel et al., 1978; Cerling et al., 2003; Kohn, 2010), a +1.5‰ correction for the fossil fuel effect (Freyer and Belacy, 1983) and a 5‰ ^{13}C-enrichment between the protein fraction of diet and collagen (Ambrose and Norr, 1993), the $\delta^{13}C$ values measured in the

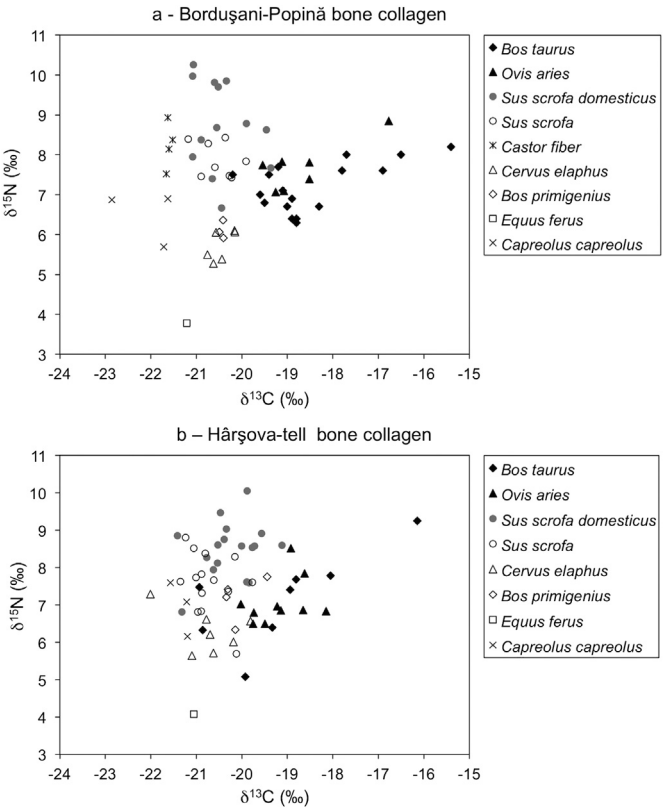

Fig. 2. Result from stable isotope analysis of bone collagen from Borduşani-Popină (a) and Hârşova-tell (b). Fig. 2a also includes 17 measurements on cattle bones (dental stages 3–5) from Gillis et al. (2013).

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wild fauna from Borduşani-Popină and Hârşova-tell reflect a C_3 plant-dominated environment.

The $\delta^{13}C$ values measured in domestic pig do not differ significantly from those measured in the wild fauna at Borduşani-Popină ($W = 52$, $p = 1$) while they are significantly higher at Hârşova-tell ($W = 178$, $p = 0.02$). Strikingly, the $\delta^{13}C$ values measured in domestic sheep and cattle from Borduşani-Popină, comprised between −20.2‰ and −15.4‰, are very significantly higher than those measured in all remaining fauna ($W = 901$, $p = 1.10^{-18}$). A similar pattern is observed at Hârşova-tell, where $\delta^{13}C$ values measured in domestic sheep and cattle vary from −20.9‰ to −16.1‰, very significantly higher than those from the remaining fauna ($W = 731.5$, $p = 1.10^{-6}$). Such high $\delta^{13}C$ values could reflect arid conditions or occurrence of C_4 plants. In modern ecosystems, the majority of C_3 plants with $\delta^{13}C$ values above −25.5‰ belong to dry environments (with mean annual precipitation lower than 500 mm/year), while $\delta^{13}C$ values of C_3 plants very rarely exceed −23‰ (Kohn, 2010). In pre-industrial ecosystems, these limit values would be close to −24‰ and −21.5‰ respectively once corrected for the fossil fuel effect (Freyer and Belacy, 1983). Considering a 5‰ ^{13}C-enrichment between diet protein and collagen (Ambrose and Norr, 1993) they would produce bone collagen $\delta^{13}C$ values close to −19‰ and −16.5‰ respectively. At Borduşani-Popină and Hârşova-tell, all $\delta^{13}C$ values over −19‰ exclusively belong to domestic sheep and cattle. The present day Dobruja province is characterized by a pronounced aridity (Lungu et al., 2011) with annual precipitation averaging 410 mm (Panaitescu et al., 2011). However, it is unlikely that this explanation is correct, otherwise the $\delta^{13}C$ values measured in the wild fauna would have been impacted to the same extant. A C_4 component in the flora, contributing to cattle and sheep diet, is a more tenable explanation.

3.3. Bone collagen $\delta^{15}N$ values

The $\delta^{15}N$ values measured in strict herbivores (sheep, cattle, aurochs, red deer, roe deer and beaver − excluding wild horses) vary from +5.3 to +8.9‰ at Borduşani-Popină and from +5.1 to +9.2‰ at Hârşova-tell. The $\delta^{15}N$ values measured in the wild herbivores do not differ significantly at both sites ($W = 339$, $p = 0.69$). The $\delta^{15}N$ values measured in the wild horse from both sites fall outside this range (+3.8‰ at Borduşani-Popină, +4.1‰ at Hârşova, Figs. 2 and 3). Although it is beyond the scope of this paper to focus on this particular point, this observation concurs with previous observations (Fig. 3) on equids from the Chalcolithic assemblages of Vităneşti (Balasse et al. 2013) and Cheia (Balasse et al., 2014) in Romania, and Varna and Durankulak in Bulgaria (Honch et al., 2006, 2013). Specific digestive physiology and/or ecological niche can be advanced to explain this difference.

At both sites, the omnivorous diet of the wild boar is reflected in $\delta^{15}N$ values significantly higher than those measured in all herbivores (excluding wild horses − $W = 248.5$, $p = 0.01$ at Borduşani-Popină; $W = 331.5$, $p = 0.01$ at Hârşova-tell). The $\delta^{15}N$ values measured in domestic pigs are even higher, averaging +8.8 ± 1.1‰ and +8.5 ± 0.8‰ at Borduşani-Popină and Hârşova-tell respectively, compared to +7.9 ± 0.4‰ and +7.6 ± 0.8‰ respectively for wild boar, and +7.0 ± 1‰ and +6.7 ± 1.3‰ respectively for herbivores. The difference observed between domestic pig and wild boar is significant ($W = 80$, $p = 0.04$ at Borduşani-Popină; $W = 192.5$, $p = 0.003$ at Hârşova; Fig. 4) and reflects a higher contribution of animal protein in the diet of domestic pigs, although the difference in the mean $\delta^{15}N$ values in pigs and herbivores (1.8‰ at both sites) does not reach the 3‰ trophic level step that would differentiate herbivores from carnivores (Schoeninger and DeNiro, 1984).

3.4. Enamel bioapatite $\delta^{13}C$ and $\delta^{18}O$ values

Results from sequential analysis of enamel bioapatite $\delta^{13}C$ and $\delta^{18}O$ are given in Table 3 and Figs. 5–7. At Borduşani-Popină, enamel bioapatite $\delta^{18}O$ values vary from −8.6 to −3.2‰ in cattle, and from −8 to −1.6‰ in sheep. The $\delta^{18}O$ sequential series vary along cattle and sheep tooth crowns according to a pattern close to a sinusoidal cycle, reflecting seasonal changes in the $\delta^{18}O$ of ingested water. These changes, primarily related to seasonal changes in ambient temperature impacting the $\delta^{18}O$ of precipitations (Rozanski et al., 1993), are recorded in enamel during tooth formation (Fricke and O'Neil, 1996). Under this latitude, the highest $\delta^{18}O$ values correspond to the warmest, the lowest to the coldest time of the year. The sequences recovered from the cattle and sheep third molars are close to a whole annual cycle. The concomitant analysis of $\delta^{13}C$ values indicates potential variations in composition of diet throughout the seasonal cycle.

Table 3
Stable carbon isotope composition ($\delta^{13}C$) of enamel bioapatite from Borduşani-Popină (PBORD) and Hârşova-tell (HVA). Maximum and minimum values measured in each tooth, middle value = (Max + Min)/2, and amplitude of intra-tooth variation.

Enamel $\delta^{13}C$ (‰)				
Specimen	Max	Min	Middle	Amplitude
PBORD Bos 28 M3	−8.1	−10.2	−9.2	2.1
PBORD Bos 29 M3	−7.6	−11.7	−9.6	4.1
PBORD Bos 30 M3	−7.1	−10.3	−8.7	3.2
PBORD Bos 31 M3	−8.9	−12.5	−10.7	3.7
PBORD Bos 32 M3	−8.7	−10.2	−9.4	1.5
PBORD Bos 35 M3	−8.1	−11.4	−9.7	3.3
PBORD Bos 37 M3	−6.4	−10.2	−8.3	3.8
PBORD Bos 39 M3	−10.8	−12.2	−11.5	1.3
PBORD Bos 41 M3	−8.2	−9.6	−8.9	1.4
PBORD Bos 44 M3	−9.6	−11.6	−10.6	2.0
PBORD Ovis 64 M3	−7.2	−12.2	−9.7	5.0
PBORD Ovis 65 M3	−8.8	−12.0	−10.4	3.1
PBORD Ovis 67 M3	−9.6	−11.8	−10.7	2.2
PBORD Ovis 70 M3	−8.7	−12.3	−10.5	3.6
PBORD Ovis 71 M3	−8.2	−12.3	−10.3	4.1
PBORD Ovis 72 M3	−8.0	−11.5	−9.8	3.4
PBORD Bos MB3 M3	−10.8	−11.3	−11.1	0.5
PBORD Cervus 10 M3	−12.2	−13.6	−12.9	1.4
PBORD Capreol 1 M2-M3	−13.7	−14.3	−14.0	0.7
HVA Bos 19 M3	−6.6	−8.8	−7.7	2.2
HVA Ovis 92M3	−8.9	−12.1	−10.5	3.2
HVA Ovis 93 M3	−9.7	−11.8	−10.8	2.1

At Borduşani-Popină, the $\delta^{13}C$ values recorded in enamel vary from −12.5 to −6.4‰ in cattle, from −12.3 to −7.2‰ in sheep teeth. Applying a 14.1‰ isotope enrichment (ε^*) between diet and enamel bioapatite (Cerling and Harris, 1999), it is possible to relate the $\delta^{13}C$ value measured in enamel to that of the animal's diet. A mean $\delta^{13}C$ value of −25.5‰ for pre-industrial C_3 plants would lead to a $\delta^{13}C$ value of −11.8‰ in enamel bioapatite. The great majority of $\delta^{13}C$ values measured in cattle and sheep from Borduşani-Popină are higher than this value. Feeding on plants from dry environment with $\delta^{13}C$ values higher than −24‰ would lead to $\delta^{13}C$ values higher than −10.2‰ in enamel bioapatite; considering that $\delta^{13}C$ values for C_3 plants would very rarely exceed −21.5‰, enamel biopatite $\delta^{13}C$ values exceeding −7.7‰ would certainly reflect a significant contribution of C_4 plants to diet. At Borduşani-Popină, the $\delta^{13}C$ values recorded in cattle and sheep enamel clearly suggest a contribution of C_4 plants, confirming observations from bone collagen analysis. Sequential analysis also reveals great seasonal variations in cattle and sheep plant diet $\delta^{13}C$ values, with amplitude of intra-tooth variation averaging 2.6‰ in cattle (maximum 4.1‰) and 3.6‰ in sheep (maximum 5‰). The lowest $\delta^{13}C$ values are recorded when $\delta^{18}O$ values are the lowest − at the coldest time of

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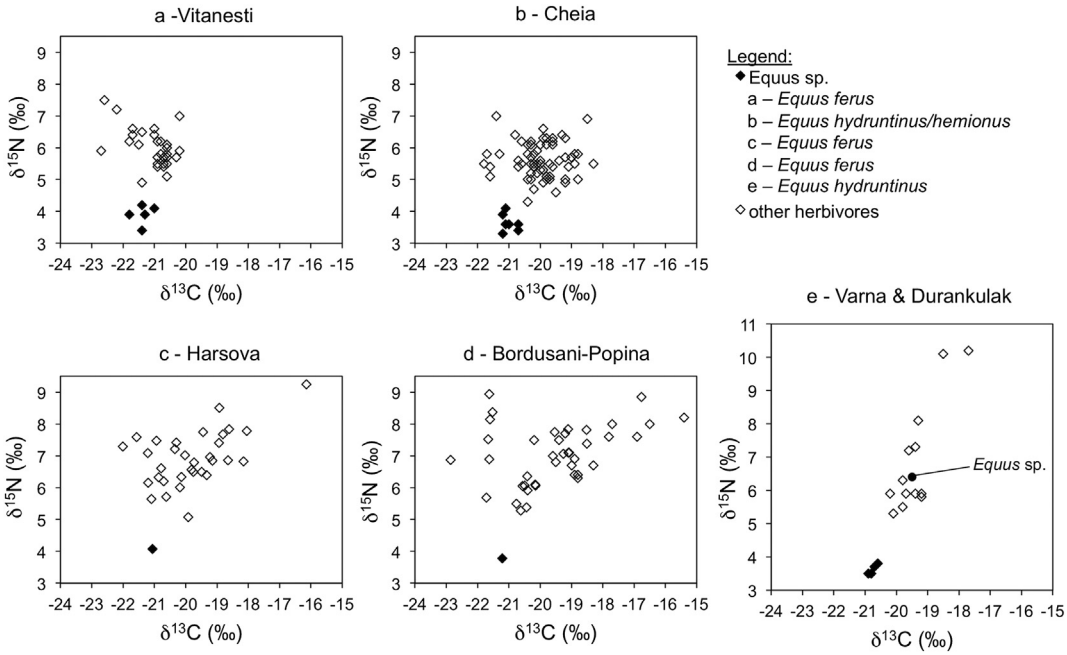

Fig. 3. Comparison of $\delta^{15}N$ values measured in bone collagen from equids and other herbivores from the same assemblages, at Vitanesti (data Balasse et al., 2013), Cheia (Balasse et al., 2014), Hârşova-tell and Borduşani-Popină (this study) and Varna and Durankulak (data Honch et al. 2006, 2013).

the year – and the highest $\delta^{13}C$ values recorded barely after the $\delta^{18}O$ values reach their maximum – at the warmest time of the year (Figs. 5 and 6). This would indicate a significant contribution of C_4 plants in summer time.

The sequences of $\delta^{18}O$ and $\delta^{13}C$ values retrieved from the cattle M3 from Hârşova-tell show a similar pattern with elevated maximum $\delta^{13}C$ values (−6.6‰) reached slightly after the $\delta^{18}O$ optimum, and minimum $\delta^{13}C$ values (−8.8‰) when the $\delta^{18}O$ values are the lowest (Fig. 5). The pattern of variation of $\delta^{18}O$ and $\delta^{13}C$ values measured in one sheep from HVA (HVA Ovis 92M3) also strongly reminds the patterns observed in PBORD sheep with more elevated $\delta^{13}C$ values in summer time, whereas the other sheep (HVA Ovis 93M3) gives an example of a summer with no contribution of C_4 plants to diet (Fig. 6).

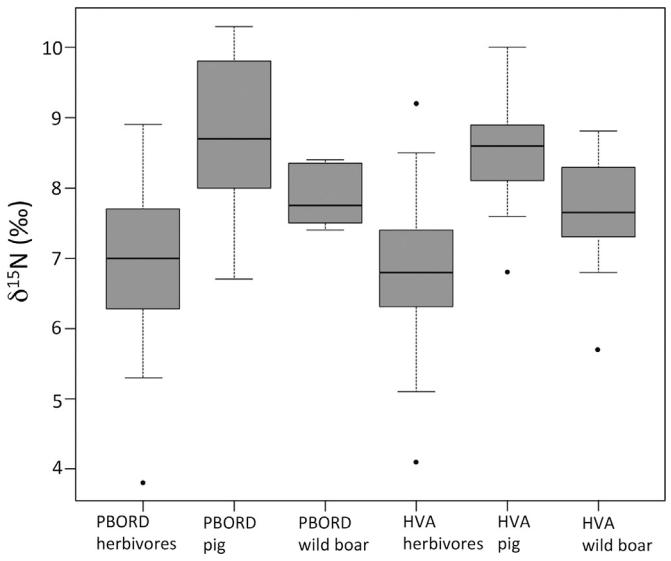

Fig. 4. Box plot of $\delta^{15}N$ values measured in bone collagen from domestic pigs, wild boars and herbivores at Borduşani-Popină and Hârşova-tell.

Sequential analyses in tooth enamel from wild taxa confirm a pure C_3 diet for aurochs, red deer and roe deer even at the seasonal scale (Fig. 7). The summer contribution of ^{13}C-enriched plant resources is not detected in the auroch's third molar, and the low $\delta^{13}C$ values measured in cervids (around −14‰) suggest feeding in forested areas.

4. Discussion

4.1. Surrounding landscape

The stable carbon isotope values measured in bone collagen and tooth enamel bioapatite of the wild fauna reflect an open environment, dominated by C_3 plants. At Borduşani-Popină, a forested component may be detected in the bone collagen $\delta^{13}C$ value measured in PBORD Capreolus 3 (−22.9‰, Table 1 and Fig. 2a). This value tends toward the average $\delta^{13}C$ value of −24.7‰ (or −23.2‰ once corrected for the fossil fuel effect) reported for modern roe deer from the Dourdan deciduous forest in Northern France (Rodière et al., 1996). This may suggest incursions of roe-deer into the forest, as highlighted by the sequential analysis in PBORD Capreolus1 M2 and M3, with $\delta^{13}C$ values as low as −14.3‰ (Fig. 7 and Table 3) referring to a $\delta^{13}C$ value of −28‰ for diet. Similar values are also observed for winter in the third molar of PBORD Cervus 10 (Fig. 7). This confirms the presence of forested areas, previously suggested by the spectrum of hunted mammals and avifauna (Moise, 1997; Bălăşescu et al., 2003; Gal and Kessler, 2003), the gathering of forest fruits and by the predominant use of oak wood in the constructions (Tomescu, 2003).

The C_4 plant component detected in some bones and most teeth from cattle and sheep is significant. The average maximum $\delta^{13}C$ value measured in cattle and sheep teeth from Borduşani-Popină, respectively −8.1‰ and −8.4‰ would correspond to a summer contribution of 26% and 23% of C_4 plants to diet. This estimation is even higher in HVA Bos19 M3, where a maximum $\delta^{13}C$ value of −6.6‰ in bioapatite would suggest 36% C_4 plants in the summer diet. These estimations are approximate and may be

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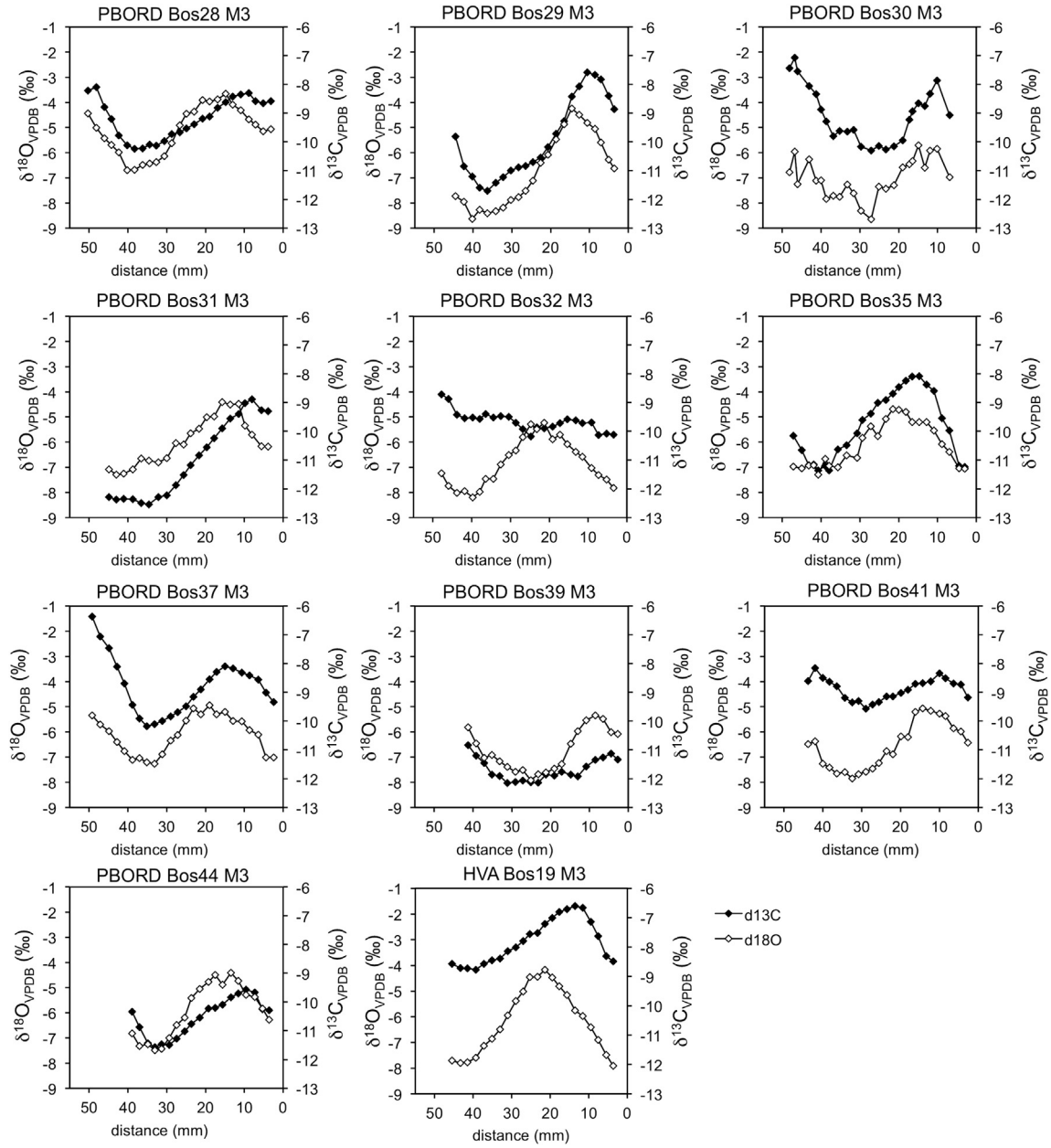

Fig. 5. Results from sequential stable carbon ($\delta^{13}C$, black symbols) and oxygen ($\delta^{18}O$, open symbols) isotope analysis of enamel bioapatite in cattle third molars (M3) at Borduşani-Popină (PBORD) and Hârşova-tell (HVA). Each sample is located in the tooth crown relative to its distance from the enamel–root junction. Data for PBORD Bos 30 M3 and PBORD Bos 35 M3 are taken from Gillis et al. (2013).

underestimated considering that a mineralisation delay in sheep and cattle tooth enamel would attenuate the optima on a sequence showing cyclical variations (Balasse, 2003; Zazzo et al., 2005; Balasse et al., 2012). C_4 plants represent only 1–2 % of species in Romania today (Collins and Jones, 1985; Pyankov et al., 2010). However, this figure may not permit an accurate prediction of the actual C_4 biomass (rather than relative frequency of C_4 species), especially at the seasonal scale. Moreover, a selective feeding behaviour for sheep and cattle may also introduce a bias for estimating the local availability of C_4 plants from their representation in diet. Finally, the fact that this C_4 component is exclusively represented in the diet of domestic stock strongly suggests it is directly related to human activities.

4.2. Cattle and sheep husbandry

From sequential analysis in tooth enamel, contribution of C_4 plants to the diet of cattle and sheep occurs at a seasonal scale (Figs. 5 and 6). This probably partly explains the great variability in the $\delta^{13}C$ values measured in cattle and sheep bone collagen (Fig. 2). At both sites, sheep were preferentially slaughtered within the first two years of life (Bréhard and Bălăşescu, 2012). In a previous study at Borduşani-Popină, the highest $\delta^{13}C$ values measured in cattle bones were from juvenile individuals fully weaned (Gillis et al., 2013). The relative weight of a seasonal contribution of C_4 plants to the $\delta^{13}C$ signature in bone is expected to be more significant in early life, when the total number of seasons contributing to the

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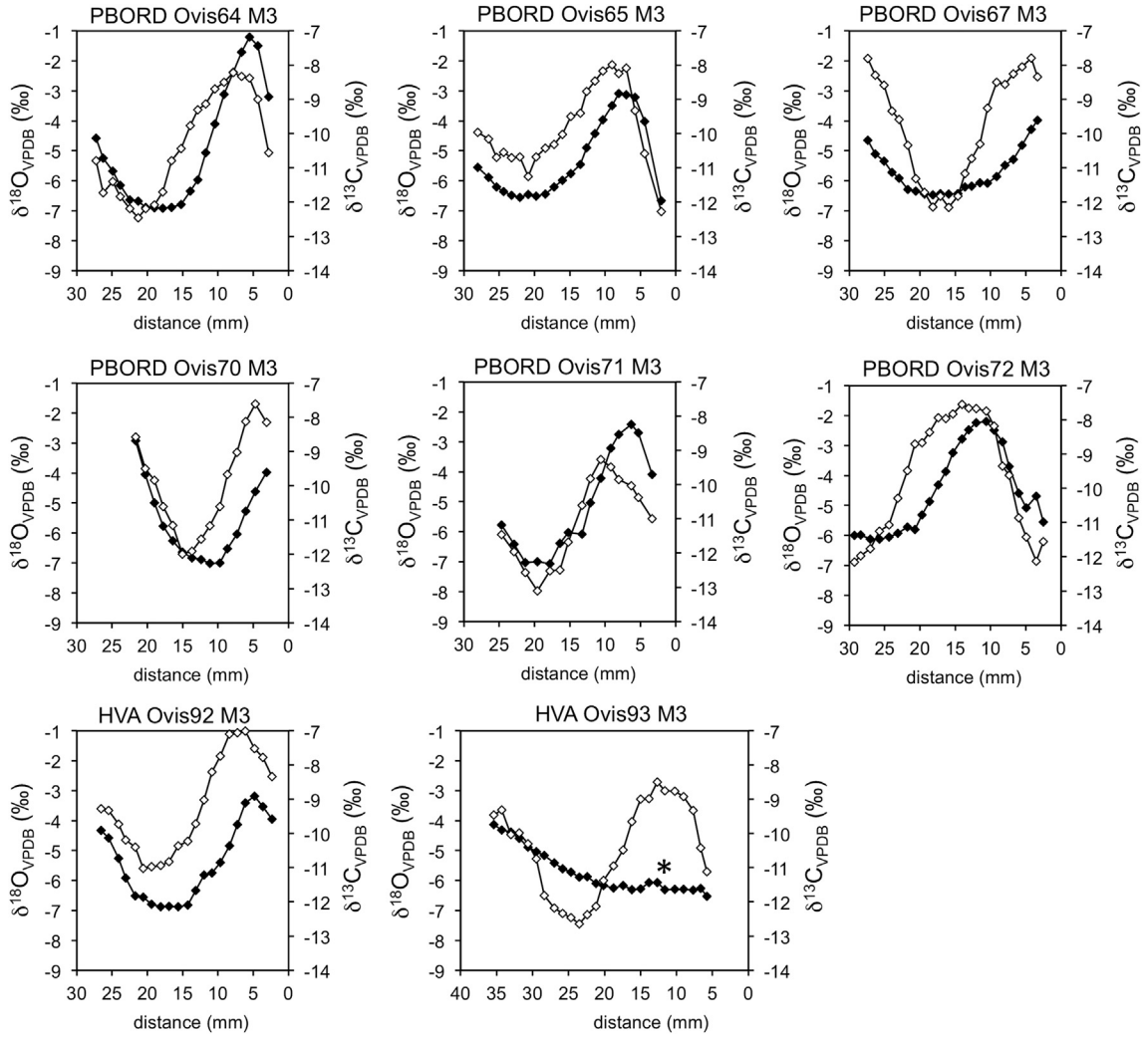

Fig. 6. Results from sequential stable carbon ($\delta^{13}C$, black symbols) and oxygen ($\delta^{18}O$, open symbols) isotope analysis of enamel bioapatite in sheep third molars (M3) at Borduşani-Popină (PBORD) and Hârşova-tell (HVA). Each sample is located in the tooth crown relative to its distance from the enamel–root junction. (*) indicates a sequence with no contribution of C_4 plants in the summer diet.

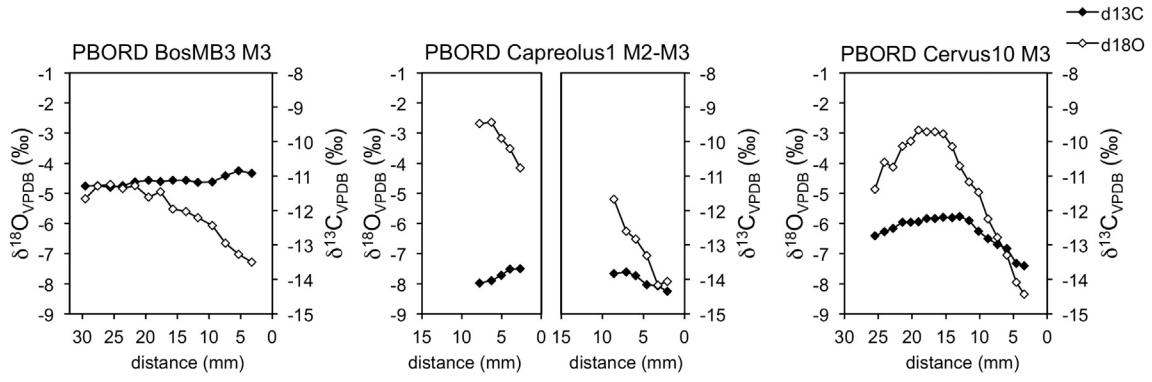

Fig. 7. Results from sequential stable carbon ($\delta^{13}C$, black symbols) and oxygen ($\delta^{18}O$, open symbols) isotope analysis of enamel bioapatite in second (M2) and third molars (M3) from the wild fauna from Borduşani-Popină.

global signal is low. Inter-individual variability may then depend on the last season recorded in bone before death.

The contribution of C_4 plants to the diet of cattle and sheep, most likely related to human activities, does not necessarily reflect introduction of cultivated C_4 plants to their diet, even though it could still be indirectly related to agriculture. Macrobotanical remains retrieved at Borduşani-Popină and Hârşova-tell (Monah, 1998–2000) have highlighted the presence of C_3 crops and pulses, but no cultivated C_4 plants. Looking at the wild component of vegetal remains, Cyperaceae, Chenopodiaceae, Amaranthaceae and

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Asteraceae are also present at Borduşani-Popină. All four families include C_4 species. Cyperaceae species, potentially occurring in the marshlands of the Danube floodplain, would be equally available for wild and domestic fauna. However, no significant contribution of C_4 plants was detected in the bones from wild herbivores. Species of Chenopodiaceae, including *Chenopodium*, and Amaranthaceae, including *Amaranthus* (attested in the archaeological assemblage) in particular, typically occur in disturbed places. They would have been more abundant around the settlement: *Chenopodium* are found around dwellings and along roads where they are often accompanied by *Amaranthus*. They are also found along domestic animal pathways and in cultivated fields. These plants would have been more readily available to the domestic animals kept in the vicinity of the village than to the wild fauna. If the feeding on these ruderal plants were to explain the C_4 component in cattle and sheep diet, this could consequently indicate that this domestic stock was spending a significant amount of time grazing by the settlements, suggesting a local scale husbandry, rather than extensive herding at a larger scale.

Bitter vetch, nowadays known for its use as fodder, did not contribute to a significant extent to cattle and sheep diet, otherwise it would have impacted their collagen $\delta^{15}N$ towards lower values. This confirms the primary interpretation by Monah (1998–2000), according to which the high occurrence of bitter vetch seeds in the domestic area suggested consumption by the human community.

4.3. Pig husbandry

In the course of the Neolithic in Southern Romania, growing importance was given to pig, starting with slight representation in early Neolithic assemblages (2–3 % of mammal remains) and finally reaching a significant place (15–20 % of mammal remains) in the Gumelniţa culture. This may be partly explained by adoption of a sedentary lifestyle, also shown by the development of tell sites (Bălăşescu et al., 2005b). In this context, the scale of pig herding at Borduşani-Popină and Hârşova-tell may help understanding the investment of pastoral societies into the keeping of this domestic species. The proximity of the flock to the settlement may be assessed by its position in the anthropic ecosystem, where trophic chains possibly include by-products from animal exploitation and land cultivation. The keeping of pigs by the village may result in its scavenging on consumption refuses, including animal products, which would raise it to an omnivore to carnivore level in the trophic chain. If herded extensively in woodland, domestic pigs would have a diet similar to that of their wild counterparts. This could be the case for example at the early Neolithic site of Măgura (Starčevo-Criş I culture), in southern Romania, where a limited number of collagen $\delta^{15}N$ values measured in pig bones reflect a primarily herbivorous diet for these individuals, suggesting extensive herding (Balasse et al., 2013).

The elevated $\delta^{15}N$ values measured in domestic pigs at Borduşani-Popină and Hârşova-tell do not suggest any significant contribution of cultivated pulses in their diet, whose consumption would have, inversely, lowered their collagen nitrogen isotope ratios. More elevated $\delta^{15}N$ values for pigs compared to wild boars give evidence of a higher contribution of animal protein in the diet of the domestic suids. This significant difference between domestic pigs on the one hand – defined as such from their small size, and wild boars on the other hand – the larger individuals, could speak in favour of a different status of the latter regarding their relationship to humans, reaffirming the usefulness of size criteria to distinguish between functionally wild and domestic suids. However, this difference on average does not erase a significant overlap between both groups (Fig. 2) and any effort in defining the status of these large suids from their diet would necessitate evaluation of size, shape and diet on the same skeleton piece (dental remains).

The observation of a higher trophic level for small pigs is most likely related to introduction of a higher amount of animal protein to their diet. If this contribution is made available through human activities, it might include hunted or harvested animal products, or husbandry products. The latter include meat or dairy product leftovers. Exploitation of cattle milk is suggested from the bovine mortality profile at Borduşani-Popină and Hârşova-tell (Bréhard and Bălăşescu, 2012; Gillis et al., 2013). However, a significant contribution of sheep or cattle products to the diet of domestic pigs would also have raised their $\delta^{13}C$ values, due to the C_4 component detected in most sheep and cattle. This is not observed at Borduşani-Popină where $\delta^{13}C$ values measured in pigs are similar to those measured in wild boars; at Hârşova-tell, $\delta^{13}C$ values measured in pigs are slightly higher than those measured in wild boars, but pig $\delta^{13}C$ values do not get higher than −19.1‰. This does not preclude a modest contribution from domestic animal products, but does not suggest that it would be a major contribution to their diet. Hunted meat may be envisaged, or, most likely, aquatic resources, which constitute a very important part of resources at Borduşani-Popină and Hârşova-tell (Bălăşescu et al., 2003; Radu, 2003). This would suggest that pigs were maintained by the village and benefited from resources gathered by the human community – directly, or indirectly from food refuses. Pigs may have been gathering resources by themselves in the rich marshland environments surrounding the settlements, including fish and small animals like gastropods, crustaceous, amphibians, reptiles or nesting birds, which naturally compose the diet of suids in the wild. However, this component alone does not seem to explain the higher trophic level for domestic pigs compared to wild boars, given that the latter could benefit to the same extent from these resources. This picture more closely resembles rearing of limited numbers of pigs in the direct vicinity of the settlement, if not household keeping, and probably a strong input of the human community in food provisioning, rather than extensive pasturing further away in the steppes, involving larger herds.

5. Conclusions

Results from the stable isotope study reveal very similar trends at Borduşani-Popină and Hârşova-tell, where the same strategies were adopted for stock rearing. The Gumelniţa communities had at their disposal the rich and diverse environment from the Danube river and its alluvial plain, from which they gathered aquatic and terrestrial resources from the wild. It seems that they also took advantage of the local conditions for husbandry: elements from the management of diet of cattle and caprines on the one side, fed at last part of the year – in the summer season – on ruderal plant species available in the direct vicinity of the dwellings, and pigs, on the other side, feeding on animal resources gathered by the human communities, suggest in both cases that domestic stocks were maintained close to the settlements.

Evidence for local agriculture is also highlighted at Borduşani-Popină, in spite of the risk for seasonal flooding of the island. First, the possibility of field cultivation in the past on the island is attested by the finding of charred barley grains (dated to Medieval or sub contemporaneous times) in a buried soil profile in the southern shore of the island sampled for micromorphological studies, and by the presence of waterlogged threshing residues (radiocarbon dated to the Chalcolithic) recovered in a lacustrine core 100 m from the site. More importantly, local agriculture is suggested by the presence at the site of waste crop processing preserved in a charred state and as impressions in the building clay,

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whereas only pure grain masses would be expected if plants had been cultivated in some places.

Concerning the relationship between local agriculture and local stock rearing, it could not be demonstrated that animal husbandry relied on cultivated crops as a source of fodder. $\delta^{15}N$ values suggest that pulses did not contribute significantly to the diet of cattle, caprines and pigs, while a contribution of C_3 cereals would not be distinguishable from wild C_3 plants on the basis of collagen or bioapatite $\delta^{13}C$ values. Indirectly, however, the significant contribution of C_4 plants to the diet of cattle and sheep, most likely ruderal plants, whose development would be favoured namely (although not only) in cultivated fields could be a sign of feeding on by-products from agriculture, either in the form of collected fodder, or resulting from grazing directly in the fields.

Altogether, these results would suggest local husbandry in a system of mixed-farming rather than large-scale specialized pastoralism. Such strategies often involve relatively small numbers of individuals, due to the necessary input from the human community to sustain the flocks' dietary requirements, to a variable but larger degree than in the case of large scale pastoralism where the herds are taken to good quality pastures according to an annual round tuned to seasonal variability in natural resources. In return, small-scale husbandry induces less investment in shepherding (Halstead, 1996). These results may have important consequences for the definition of the occupation of territory by Gumelniţa communities and the local/regional scale of the pastoral system. From the structure of caprine kill-off patterns at Borduşani-Popină and Hârşova-tell, highlighting a lack of the youngest age classes in the assemblages recovered at both sites, Bréhard and Bălăşescu (2012) suggested that lambing may have taken place elsewhere. The sites would then have been part of a larger pastoral system, including other places or sites with complementary functions. Functional complementarity in time, at the seasonal scale, is not made explicit in this model, although it may as well be conceived without this time dimension. However, if seasonal mobility would have to be introduced in the model, historical accounts of transhumant sheep herding in Romania suggest wintering in the Danube floodplain (Goia, 2012). With the significant contribution of local ruderal C_4 plants in caprines' summer diet at Borduşani-Popină and Hârşova-tell, our results suggest that caprines were also present at the sites in summer. This does not argue in favour of large-scale seasonal mobility. Bréhard and Bălăşescu (2012) underline that complementary between places does not necessarily mean a regional scale pastoral system but could involve local scale organisation: lambing would occur at designated places close to the site, still escaping from the archaeological record. In the light of our data, we would favour this hypothesis.

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